

derived from clubs, bows or arrows, and may be referred to the weapons of the twin War Gods.

The opposing players are frequently the representatives of the two War Gods, and gaming implements are among the objects sacrificed upon the altar of the Twins Zuñi. In general, games appear to be played ceremonially, as pleasing to the gods, with the object of securing fertility, causing rain, giving and prolonging life, expelling demons, or curing sickness. There is no direct evidence of the employment of games in divination, apart from an observation by Cushing.

The game of hoop and pole, like the dice game, was played throughout the entire continent north of Mexico. It consists essentially in throwing a spear or shooting an arrow at a hoop or ring, the counts being determined by the way in which the darts fall with reference to the target. The game is remarkable for the wide diversity in the form of the implements employed, as well as in the method of play. A common and most widely distributed form of the hoop is twined with a network resembling



FIG. 2.—Altar of War God, Zuñi, New Mexico, with corn-cob darts used in the ring (or hoop) game. From a photograph of the reproduction in the United States National Museum.

a spider's web, the counts being determined by the particular holes which are penetrated by the darts. The author regards the plain hoop as a modification of the netted hoop, which represents the net shield of the twin War Gods. This object, which the Twins derived from the Spider Woman, is a feminine symbol, and may be used as an amulet. The dart or arrows are masculine. Dr. G. A. Dorsey, who has studied the symbolism of the ring employed in the Sun dance of the Arapaho, says it is symbolic of the creation of the world, for it represents the sun, earth, sky, water, and wind. Although Mr. Culin states "there is no record of women participating" in this game, it is played, as he himself notes, by Hopi maidens as a part of the prolonged Oraibi Oaqöl ceremonies (H. R. Voth, Field Columbian Museum, Anth. Series, vi. [1903], p. 42). Though this cult is largely concerned with producing rain, it seems to be essentially a germination ceremony, and probably has reference to the maturation of the maidens. Mr. Culin adduces other

evidence in support of a fertility significance for this game, but he does not make any special allusion to it. Amongst some tribes the game is mythologically connected with the increase of buffalo; indeed, the Cheyenne and other Plains Indians call it the "buffalo game." The game had a religious character among the Apache, and probably this held good everywhere.

Probably connected with the foregoing is the widely spread game played by one person which consists of catching a ring, perforated object, or a ball on a peg. Dr. G. A. Dorsey says the Klamath always play it in winter; it is called "splitting or punching out the moon," and in this way the winter months are shortened and the advent of spring is hastened.

Ball games are well developed in North America, and Mr. Culin deals with them as fully as possible. The game of cat's cradle receives some attention, and various figures are illustrated, but as no instructions are given as to how they are made, much of the information is of little value. Mrs. Jayne's remarkable book on the subject is not referred to, neither is the magical aspect of the game among certain Eskimo as recorded by Boas on the authority of Captain Comer. The holy spiders taught the game to the Navaho, but calamity would befall if it were played at any other time than winter. The Zuñi explain cat's cradle as the netted shield of the War Gods, the game having been taught to them when little boys by the Spider Woman for their amusement. Owing to the ubiquitous nature of this pastime, it is evident that the Zuñi explanation of its origin is purely secondary, and was invented to bring it into their mythological system. We may suspect that the same may have happened for the hoop and pole game, in spite of Mr. Culin's belief that the oldest forms of existing games occur in the southwestern United States. Lack of space precludes due mention of the numerous minor amusements described by the author, though they are of considerable interest.

In introducing the memoir, Prof. W. H. Holmes, Chief of the Bureau, states that "the paper practically creates the science of games, and for the first time gives this branch its proper place in the science of man." This eulogy is somewhat exaggerated, as others on this side of the Atlantic have directed attention to the ethnological value of the study of games, and while Mr. Culin has produced a memorable monograph of lasting value, he can hardly be said to have introduced therein any general principles that had not previously been enunciated.

A. C. HADDON.

NERVE AS A MASTER OF MUSCLE.¹

WE have on the table before us two muscles. The animal was dead when they were taken from it a short while ago. But the animal was, as we are ourselves, an assemblage of organs, and many of these organs go on living for a certain time after the animal, as an animal, is dead. Hence these muscles, carefully removed, are still alive. We notice a marked difference between their behaviour now. To understand the behaviour of organisms we have to think of them as processes rather than as structures. An animal is something happening. The function of muscles is to contract. Of the two muscles now before us, one still goes on contracting, although quite isolated from the body of which it formed a part; but the other does not contract, although that is its function in the body. The muscle which still goes on contracting is the heart; the other is a muscle like the biceps of our own arm. We might think that, as it rests there motionless, it is not alive. It is, however, fully alive. We can satisfy ourselves of that. If I apply to it a faint electric current, it answers by exhibiting its functional activity—it contracts. Yet it does not contract of itself, nor will it, however long we may preserve it; it will die without of itself even contracting once. What is the significance of this difference between the two?

The secret of this difference is largely an affair of the nervous system. The tie between muscular activity and nervous activity is always close; but it is very different in

¹ A discourse delivered at the Royal Institution by Prof. C. S. Sherrington, F.R.S.

different muscles. The nervous system has been called, with a picturesque truth, the master-system of the body. It controls the action of organs; it controls, quite especially, the activity of the muscles. This heart which we see beating here receives nerves. One of those nerves when stimulated will cause it to contract less, the other to contract more. The contraction of the heart is its "beat." The vagus nerve slows the beating, the other nerve quickens the beating.

The heart is a tubular muscle; it drives blood through itself. When it contracts it squeezes the blood from it into the arteries, and so the blood flows to feed all the myriads of minute lives—cells—composing the whole complex living animal. The lives of these myriad minute entities all depend on their supply of blood, and therefore the life of the whole creature depends on the contraction of the heart. At each beat the heart by squeezing the blood out of its arterial end maintains the flow of blood, and this flow resulting from its own contraction refills it, because the blood returns to it by the veins.

This beating is all which the heart has to do. Whatever happens it must continue to do this, or the creature perishes. Life-long, night and day, winter and summer, it must do this. Whatever act the creature may be accomplishing, sitting, walking, feeding, sleeping, catching its prey, or escaping its enemies, this beating must go on, in the frog about ten times a minute, in ourselves about seventy times a minute. The task is monotony itself. How admirably is the heart muscle adapted to fulfil it!

Self-adjustment to meet the environmental conditions differentiates animate from inanimate nature. As characteristic as this self-adjustment itself is its constant trend toward what has sometimes been termed "purpose." Animate objects are observed to adjust themselves to their own advantage, that is, so as to prolong their individual existence or that of their species. The more we know of them the more complete appears to us this trend in their reactions. The living organism advantageously adapts itself to its surroundings; and every part of a living organism exhibits this power. The heart-muscle reveals it clearly. It must not tire, and in normal circumstances the healthy heart, unlike other muscles, shows no fatigue. Its beat must always be strong enough to press its contents over into the artery against considerable resistance which opposes it. A heart-beat which did not expel the blood would be useless, worse than useless, wasteful, because it would be energy spent in vain. Its task can be roughly likened to that of a man with a bucket who has to keep lifting water from a tank at his feet to pour it over a wall of certain height before him. If he lift the bucket much above the wall he expends more energy than he need do; if he lift it less than the wall's height his work fails altogether. If he still, when the bucket is emptied, keep it above the wall's height, his work stops, although his effort does not.

The heart, whether its stimulus be weak or strong, beats always with sufficient power; it thus avoids the useless labour of a beat too weak to fulfil the office of a beat. If the heart were to give too prolonged contraction it would defeat its own purpose; after its beat, which empties it of blood, it must relax to refill for the next beat; to keep contracted would be for its purpose as harmful as to cease from beating; it would stop the blood instead of pumping it onward. In harmony with this, we find a prolonged stimulus to the heart does not keep the heart contracted; after the heart has replied to the stimulus by a beat it exhibits a refractory phase, during which it pays no attention to the further stimulation, and relaxes; and only after it has fully relaxed does it again pay attention to the stimulus and contract, that is to say, beat again. In short, it replies rhythmically to a continued stimulus which would keep the other muscle continuously contracted.

That the heart should go on beating after removal from the body does not seem greatly surprising, because it is still then alive. The wonder lies rather in its continuing to live so long when thus removed; that granted, it seems natural that it should do what it has done previously all its life.

But this other muscle, which likewise continues to live when removed from the body; it, though it *can* contract,

does not. That seems—at least at first sight—the more remarkable. Why does this muscle stop? So long as it was part of the living creature it showed contraction over and over again. We must turn to the nervous system for our answer.

In the first place let us note that an animal, unlike that other great example of life, a plant, cannot nourish itself from naked earth and air alone. The plant strikes down roots and throws up leaves, and draws through these material and energy with which it can replenish its own substance and activities. Where it as a seed fell, there its foster-mother Earth gives it the food it wants. Not so the animal. It must have subtler and rarer stuffs, or die. The material it needs is not spread so broadcast. It, to replenish itself, must have more special material; it must have for food material that is living, or has lived. To obtain this it has to range about. It has to hunt for it; and it itself is hunted by other animals following the same quest. Therefore its very existence involves locomotion. It must find food and seize it, and must itself escape being found and seized. It is both hunter and hunted. Moreover, in a vast number of cases it has to seek its kind to propagate its species. The movement necessary in this great game of life is million-sided—subtle beyond words—and most animal lives are spent in nothing else. Existence for the individual and the race depends upon success in it. Man plays it also—let us hope that sometimes he plays something else as well. In all cases the chief instruments of the game are the skeletal muscles, those muscles of which the biceps of our arm may stand as type. An old philosophic adage has it that all which mankind can effect is to move things. The dictum illustrates how supremely chief an executant of man's activity his muscles are. All the things which man can move are moved in the first instance by that prime thing which he can move, his body; and for this his main agents are his skeletal muscles. These execute his movements, but in doing so are but the instruments of his nervous system. Therefore it is in reality the nervous system which is the player of the game; and it is because it is really the nervous system which is the player of the game that man is the most successful creature on earth's surface at the present epoch, for his is the nervous system which, on the whole, is the most developed, much best adapted to dominate the environment.

To understand a little how the nervous system compasses this end we may turn to examine its performance in some of its simpler governing of the muscles. Its main office is to react to changes in the environment. The animal body is provided with a number of organs specially attuned to react to changes in the environment. These changes, in so far as they excite these organs, are termed stimuli. Thus, it has organs stimulated by the radiant energy of light and heat, others by chemical particles drifting from odorous objects, others mechanically by objects touching the skin, and so on. These organs, specially adapted to environmental stimuli, are called *receptors*. Attached to them are nerves. Through these the excitement set up in the receptor by a stimulus spreads to the general nervous system. Arrived there, two kinds of effect ensue from it—one, a change in nerve-cells innervating muscles and glands, the other, a change in consciousness on the basis of sensation. These two effects are separable. The former, or "reflex" reaction, is not necessarily accompanied by any manifestation of the latter, though it may be so, and very often is so. We will confine ourselves to the former, or purely reflex effect, and to its operation on muscle.

The endowment with receptor organs is not equally rich in all parts of the body. It is the external surface of the animal which, as we might expect, has them in richest profusion; and the receptors of the external surface are likewise those most developed, specialised, and sensitive. This also we might expect; for it is the external surface that for countless ages has felt the influences of the illimitable outside world playing on it. Through refinement of the receptors of its outer surface the animal has been rendered sensitive in many cases to stimuli delivered even by the remotest stars.

It is a feature of receptors generally that they react most to their agent when the intensity of that agent

changes, and the more so the more abrupt the change. It is, therefore, changes in the outside world that operate especially as stimuli, though, of course, only changes which have relation to the animal in question. If we regard the mutual relation between the animal and the world at any moment as an equilibrium, then we can say that any change in the world which changes that relation disturbs the equilibrium.

Take the instance of a child asleep. A thousand agencies of the external world are playing upon it. Upon its skin, for instance, there is the pressure of the child's own weight against the receptors, and there is the pressure of the clothes which cover it; yet it lies restful. Suppose we touch its foot. That is a change in the external world in relation to the child. The familiar fact is that the foot is drawn up out of harm's way, as it were. The change has acted upon the child as a stimulus to some receptors of the skin. It may be quite unconscious of the touch, for its sleep may be deep. Yet the reflex action has occurred, and has done the appropriate thing. A candle may be brought into the room and its light reach the face of the child. That is a change in the outside world in relation to the child. The familiar fact is that the child's head turns from the light. It sees no light, but reflex action averts its face. Or, turning to other forms of life, take a fish quiet in its aquarium. A worm is dropped into the water, and the disturbance of the water reaches the surface of the fish. The fish turns and seizes the morsel. Such a reaction on the part of such a creature is probably wholly reflex.

The point for us here is, that the changes in the outside world which act as stimuli bring about appropriate readjustments of the body to the external world, and that in doing so the instruments of readjustment are the skeletal muscles, worked by the nervous system. The child's heart goes on beating, whether the child's foot lies quiet or is moved, whether its face lies this way or lies that; the fish's heart whether the animal's skin was stimulated by fresh commotion in the water, or was not. But with the skeletal muscles it was different. Flexor muscles of the leg, that were relaxed, are by the touch to the foot thrown into action; muscles which lay relaxed were, when the light came, caused to contract, turning the head away. Muscles of the fish that were inactive were thrown into activity by the new commotion in the water. It is these skeletal muscles, therefore, that the daily thousand changes of the external world so repeatedly and constantly affect in this way or that, and in reflex action it is always the receptors and the nervous system which impel them to react; and the result is to re-adjust advantageously to the animal its relation to the altering external world. Hence these muscles are called the muscles of *external relation*. So prominent are these muscles in the everyday work of life that they are the muscles of ordinary parlance. The man in the street is hardly aware that he has in his body any other muscles. These muscles are, through the nervous system, driven by the external world. The world outside drives them by acting on the receptors. It is not surprising, therefore, that this little muscle, removed from the body, and therefore separated from the nervous system and all its receptors, remains, although still living and able to contract, as functionally inactive—for contraction is its function, and it does not contract—as if it were already dead.

Now this muscle, when in the body, was the servant of a thousand masters. It had to contribute to a thousand acts. In a certain sense, it, like the heart, had to do for them all but one thing, inasmuch as it had to pull the limb in one certain direction; and yet its task is a very varied one. It has to pull the limb sometimes far, sometimes very slightly, or through all intermediate grades. It has to pull it strongly against great resistance, or weakly, and with all intermediate grades of intensity. We may suppose that in the course of evolution it had become adapted to this scope of purpose.

And indeed we find it so. Unlike the heart muscle, this muscle when a strong stimulus is applied contracts strongly, when a weak stimulus, weakly; under a long stimulus it contracts long, under a brief, briefly. The nervous system, in making use of this muscle, wants of it just such varied action as this—now weak, now strong,

now brief, now long, as may be suited to the act required. The little organ is admirably adapted to be the animal's instrument in the world in which it is placed. This muscle has its place in the economy of nature, and into it it fits as a key into the lock for which it has been made. Man's naive view, until somewhat recently, was that the earth and the universe were made to fit him. Was the universe made to suit this little muscle or was this little muscle made to suit the universe? The problem concerning this muscle and that concerning man are, in so far, the same. Surely our answer is that the muscle and the rest of the universe fit each other because they have grown up together—because they are part of one great whole; they fit just as a lock and key fit because they compose one thing, and it is pointless to ask whether the lock was made to fit the key or the key the lock.

The office of the nervous system is to coordinate the activities of the various organs of the body, so that by harmonious arrangement the power and delicacy of the animal's mechanism may be obtained to the full. When reflex action withdraws the foot of a sleeping child, it is not merely one such muscle as this which moves the limb, but many. The limb has many muscles, and even in such a simple act many and many of them are employed.

That the act occurs during sleep shows that consciousness is not its necessary adjunct. A similar act can be similarly evoked in an animal when the brain—the seat of consciousness—has been removed. The brain can be removed under deep narcosis of chloroform without any pain or feeling whatsoever. After that removal the animal is no longer a sentient or conscious thing at all. Then we can study in it the power of reflex action sundered from conscient and sentient life altogether. Then it is that opportunity is given for further reverent analysis of those wonderful and subtle workings of the nervous system which in ourselves are so difficult to unravel for the very reason that their working goes on without appeal to, and often beyond access of, the conscious self.

When analysing the muscular action of even so simple a reflex act as that of drawing up the foot, a fact which early meets the observer is that the nervous system treats whole groups of muscles as single mechanisms. In lifting the limb it employs together muscles, not only of one joint of the limb, but of all the joints—knee, hip, ankle, &c. It deals with all these muscles as if they were but one single machine. If the movement is forcible, it throws them all into strong contraction; if weak, into weak. In the grading of the reflex action its influence is graded in all these muscles alike. So also the contraction in all of them is timed to begin together, to culminate together, and to desist together. Further, although the movement of this lifting of the limb is mainly flexion at its joints, the reflex accomplishes along with that some internal rotation of the hip and some abduction of the thigh. Why it should do so we shall see presently. Suffice us for the present that, besides the flexor muscles, the nervous system brings into play, at the same time and harmoniously with those, two other great groups of muscles, the internal rotators and the abductors. So perfect is its skill in using the muscles as its instruments that it can deal harmoniously and simultaneously with all these individually complex groups of motor organs as though they were but one.

Were we to attempt to produce this movement in the limb experimentally without employing its nervous system, we should have to apply I know not how many stimuli simultaneously to more than half the muscles of the limb. Not only that, but we should have to grade the stimulation of each of these most accurately to a particular strength. We should also have to arrange that, not only did each stimulus develop its full strength with the right speed, but that each should maintain it for the appropriate time and desist at the right speed and moment, and with proportioned intensity. Moreover, in the real reflex act the contraction of this or that muscle is now stressed, now subdued, with a delicacy and accuracy baffling all experimental imitation. The coordination in even the simple reflex we are considering may be likened to that exhibited by a vast assemblage of instruments in very perfect orchestration directed by a supremely capable conductor.

But it is more subtle and delicate than that, even in

the simple reflex we are considering. The coordination goes much farther than we have yet assumed. The musculature of the limb is an instance of that kind of musculature which obtains where parts are adapted to move, not in one direction only or one way only, but in many. The limb has to do many different things. It has, according to circumstances, to bend or to straighten, to turn inwards at one time, at another to turn outwards, to move this finger or move that. Its musculature is therefore split up into many different muscles—some doing this, some doing that. Hence it comes that in the limb are muscles which when they contract do with the limb exactly opposite things. Thus we find a set of muscles which bend the knee, and another which straighten the knee; so, similarly, at hip and ankle, at elbow, shoulder, and wrist. These muscles of opposed action are called antagonists. Now in the flexion reflex—the reflex we are considering—when the reflex bends the knee by causing the flexor muscles to contract, what happens with regard to the muscles which straighten the knee? Do the opponents, the muscles which straighten the knee, contract, or does the reflex nervous influence leave these muscles untouched? It used to be taught that the muscles which straighten the knee, the extensor muscles, contract, and by their contraction exert a moderating influence on the muscles which execute the flexion. That was the anatomical speculation deduced from simple dissection of the musculature of the dead limb. Experiment with the living limb teaches that nature does not expend her muscular energy in using the power of one muscle simply to curb the power of another. When the knee is bent the reflex act does not hamper the working of the flexor muscles by causing a contraction of the extensors also. Nor does it simply leave the extensors out of account. No; it causes them to relax and lengthen at the same time as it causes the flexor muscles to contract and shorten. This it does by reflex *inhibition*; and it proportions the grade of this relaxation exactly to the grade of contraction of the opponent muscles.

The inhibition acts, not on the muscle directly, but on the motor nerve-cells innervating the muscle. These nerve-cells are long filaments; one end of each lies in the muscle, the other in the spinal cord. The reflex inhibition is exercised upon them at the end which lies in the spinal cord. In the reflex we are considering, the reflex action, besides *exciting* the motor nerve-cells of the three muscle groups—flexors, abductors, and internal rotators—before mentioned, *inhibits* the motor nerve-cells of three muscle groups antagonistic to those, namely, the extensors, the abductors, and external rotators. We see, therefore, that in even the simple reflex lifting of the foot, almost every one of the many muscles composing the whole musculature of the limb receives from the nervous system a controlling influence, either of excitation to contract or of inhibition which relaxes contraction; and all this in result of a simple touch of the skin of the foot. The reaction typifies in a simple manner the action of the nervous system to knit the heterogeneous powers of the body together into one harmonious whole.

Thus we see that in these actions when one group of muscles contracts the group antagonistic to it relaxes. This is a fundamental part of the coordination of the act, and its discovery throws a welcome light on the nature of certain maladies. Were the antagonistic group to contract at the same time as the protagonist, the desired movement would not result. The movement which then ensued would depend on which of the two muscle groups were the stronger, the protagonist or the antagonist. The alkaloid strychnine and the poison produced by the bacilli which cause the malady called "lock-jaw" possess the power of destroying reflex inhibition. What the intricate nature of the process of this inhibition is we do not yet know, but it seems to be the exact converse of the process of excitation, the nature of which is also unknown. Strychnine and tetanus-toxin change the process of inhibition into its converse, namely, excitation. If a minute dose of strychnine be administered, the reflex which, as we saw, causes the limb to bend, now causes the limb to straighten instead. This is because the extensors, when the flexors contract, instead of being relaxed by inhibition, are excited to contraction, and being more powerful than

the flexors move the limb in exactly the opposite direction to that in which it should move in this reflex action. Similarly with the toxin of "lock-jaw." The muscles which close the jaws are much more powerful than those which open them. In the normal act of opening the mouth the relatively feeble opening muscles contract, and the powerful closing muscles are simultaneously relaxed by reflex inhibition. But in an animal or man poisoned with this toxin the normal inhibition of the closing muscles is changed to the exactly opposite process of excitation, so that their contraction results. Against the power of these strong closing muscles the contraction of the weak opening muscles can effect little. Each time, therefore, that the sufferer tries to open his jaws to take food or speak, he clenches his jaws instead of opening them—experiencing a torture which, although unaccompanied by physical pain, is inexpressibly distressing; and the disorder leads to death from inanition.

But to return to the reflex lifting of the leg, whence we set out. It was mentioned that in this reflex the limb was not merely lifted, but was slightly rotated inwards at the hip, and that the thigh was slightly abducted, that is to say, drawn sideways, separating it more from the fellow-limb of the opposite. These accessory movements have a significance coinciding with much other evidence into which we have not time to enter now. They, together with other evidence, show that this lifting of the leg, so easily produced reflexly, is nothing more nor less than the first movement of the taking of a step. In fact, in our rough and imperfect analysis of this little movement, we have been examining part of the great and extraordinarily complex and perfect act which is called walking—or more technically, so as to include the cognate acts of trotting and running—locomotion. A little reflection will suffice to assure you that included in the action of locomotion is also that of standing. We are apt to forget that the muscles have a static as well as a kinetic action—that they are the instruments of maintaining position, as well as of the execution of movements. Directly we begin to analyse locomotion we see that its basis, as it were, is the position of standing, upon which movements of stepping are, as it were, grafted. Not much is known as yet of how animals and ourselves stand, walk, and run. In these acts, probably, every skeletal muscle in the whole body is concerned. Rheumatism can make us aware of that. A little receptor organ in the ear is a great factor in the whole matter. But of this we may be sure, that foremost in its factors are reflex actions of the limbs. Great economic questions are involved in this unravelling of the act of locomotion—all beasts of draught and burden are chiefly useful to us because they can stand, and walk, and run. We can only employ their powers to full advantage and with due regard to them as they unfold these powers when we shall have learnt something of the way in which these movements are conducted and performed.

The crude and imperfect analysis which I have attempted to outline concerned but *one phase* of the step of a *single* limb. In the complete act the other limbs will at the same time be executing other phases of the whole cyclic reflex. The neck and trunk are also involved; so, likewise, the head itself. Our imperfect analysis threw sidelights on the nature of the mischief wrought by strychnine-poisoning and the malady "lock-jaw." Interesting and useful though these sidelights may be, more really interesting and valuable would be any light which such analysis, crude as it is, could throw on that great normal process of everyday health, animal (including human) locomotion. Analysis of the reflex movement in unconscious animals seems at the present time the only way by which such knowledge can be gained.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—Lord Rayleigh was on April 10 unanimously elected Chancellor of the University in succession to the late Duke of Devonshire. It is expected that the inauguration and the installation of the new Chancellor will take place during the May term.